MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

Rationale for Missouri Numeric Nutrient Criteria

September, 2015

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Introduction

In August, 2011, EPA disapproved Missouri's numeric nutrient criteria (NNC) for lakes (10 CSR 20-7.031 (3)(N)), A portion that was approve (Table M) sets NNC for only 26 of Missouri's water bodies, with criteria being site-specific and based on long-term average conditions. The Missouri Department of Natural Resources, with the input of stakeholders, is revising the rationale for criteria development to provide a significant link between the criteria and the designated uses (DU) of lake waters. In particular, the efforts are concentrated on the protection of aquatic life and drinking water supply.

All classified lakes in Missouri have at minimum the following designated uses: aquatic life protection (AQL), human health protection (HHP), whole body contact recreation – Category B (WBC-B), and Secondary contact recreation (SCR). A number of lakes have additional DU, including whole body contact recreation – Category A (WBC-A), and drinking water supply (DWS) (Missouri Secretary of State, 2014).

A complicating factor in deriving appropriate NNC is that Missouri lakes are almost all reservoirs. These man-made impoundments render reference approaches to nutrient criteria development moot, as the water-bodies are themselves a significant human influence on the landscape. Also, the relatively recent construction of these reservoirs precludes the use of approaches to NNC development that focus on historic conditions (Kennedy, 2001).

Another complicating factor is that optimal trophic conditions for a designated use do not necessarily coincide with optimal conditions for other uses. In particular, AQL favors a relatively high availability of nutrients to supply the food chain (Michaletz, Obrecht, & Jones, 2012; Downing & Plante, 1993; Ney, 1996). In contrast, DWS and WBC are optimal at lower nutrient content, which enhances water transparency and reduces the production of taste and odor compounds, disinfection byproduct precursors, and algal toxins (Falconer, et al., 1999; Knowlton & Jones, 2003).

Trophic state refers to the biological production, both plant and animal life, that occurs in a lake or reservoir. All trophic classification is based on a division of the trophic continuum, of which there are no clear delineation of divisions (Carlson, 1977). Lakes with low nutrient concentrations and low levels of algal production are referred to as oligotrophic. Water-bodies with high nutrient levels and productivity are termed eutrophic. Mesotrophic lakes fall in between this continuum. Hypereutrophic lakes fall on the extreme high end of this continuum and are characterized by excessive nutrients and are extremely productive in terms of algal growth. In these systems algal blooms may be frequent and severe. These blooms can lead to oxygen deficits when the bloom dies off and bacterial decomposition of the organic matter is maximized. Low oxygen concentrations can in turn negatively affect the aquatic life within the lake.

There is a relation between geographical location and the occurrence of trophic conditions in Missouri lakes (Jones & Knowlton, 1993, Jones, Knowlton et al, 2008, Jones et al, 2009). Lakes in the northern and western parts of the state (Central Dissected Plains and Osage Plain) tend to be more eutrophic and hypereutrophic while lakes in the Ozark Highlands regions are generally mesotrophic and oligotrophic. Lakes in the Ozark Border region have a range of trophic states that are generally lower than the Plains region but higher than the Ozark Highlands (Jones, Obrecht et al., 2008). These regional differences in water quality reflect geological and topographical differences across the state.

The current revision takes into account aquatic life and drinking water protections assigned to lakes within each of the ecological regions. Lakes that are used for DWS have criteria that are specific to that use within the Plains region. Lakes in the Ozark regions have more conservative NNC for AQL than for DWS. Since all lakes are assigned AQL, and the most protective use governs the criteria, there is no distinction made for DWS in these regions. Distribution of lakes in the ecoregions is described in Table 1.

At this time, lake NNC are not being developed for HHP, WBC-A, WBC-B, or SCR. Data are currently insufficient to establish a link between lake nutrient concentrations and risks associated with fish consumption. Additionally, the appropriate criteria for protection of WBC and SCR are relatively subjective and have not been agreed to at this time. Further input is being sought from the public to determine what degree of water clarity is desired for suitability of this use.

Table 1. Distribution of Lakes in Missouri Ecoregions.

Lake Class	Description	Plains	Ozark Border	Ozark Highland
L1	Lakes used primarily for public drinking water supply	103	3	5
L2 (DWS)	Major Reservoirs that include DWS	4	0	3
L2 (Other)	Other major reservoirs	1	0	7
L3	Other lakes	525	151	245
Totals		633	154	250
Grand Total		1,037		

Setting Criteria

Both causal (e.g., phosphorus and nitrogen) and response (e.g., turbidity and chlorophyll-a (chl-*a*) variables were evaluated to develop Missouri's recommended lake nutrient criteria. Causal variables are linked to biological responses (i.e., increase in primary productivity), and when in excess, can cause water quality impairments associated with accelerated algal growth which has several adverse consequences on designated uses. These include reductions in dissolved oxygen caused by algal respiration and decay, unsightly blooms, reduced water transparency and, in some cases, the production of microcystins and other toxins by certain algae species, notably some of the cyanobacteria or blue-green algae.

Conceptually, the link between nutrient sources and designated uses is systemic involving multiple steps (Figure 1). Whereas traditional stressors are typically directly toxic, nutrient over-enrichment effects are systemic (e.g., nutrients drive productivity, which can deplete oxygen, causing detrimental impacts on organisms). Additionally, biological responses to nutrients can vary based on site-specific factors. For example, flushing rates, which vary between reservoirs, may limit the impact of phosphorus loading on water column concentrations, which ultimately stimulate phytoplankton production (EPA, 2000). Grazing pressure and turbidity also serve as confounding factors.

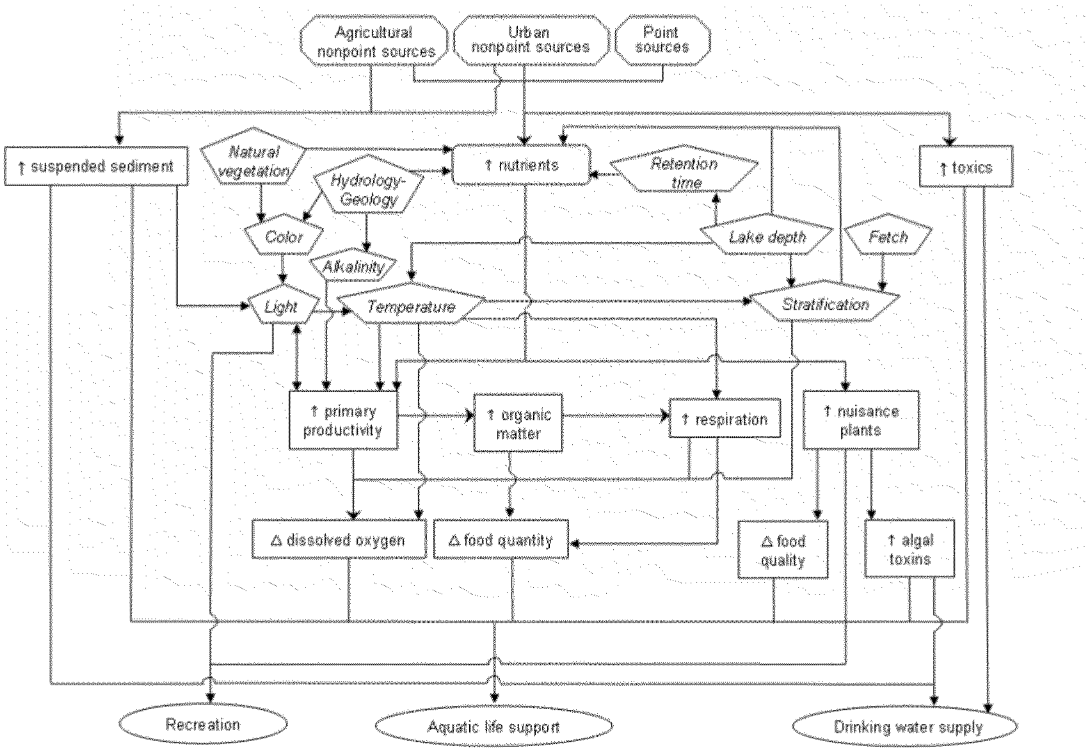

Figure 1. Conceptual Nutrient Model Diagram for Lakes (USEPA, 2010)

Establishing numeric nutrient criteria is further complicated by the fact that there are few natural lakes in Missouri. Reservoirs differ from natural lakes in that they exhibit a trophic gradient as they lose nutrients through settling in the downstream direction. A reservoir may naturally range from eutrophic in its upper reaches to oligotrophic near the dam. Reservoirs also tend to have lower chl-*a* levels at the same phosphorus concentrations than natural lakes due to higher inorganic turbidity and flushing rates (Soballe & Kimmel, 1987)

Empirical links between chlorophyll and phosphorus have been extensively studied and are well established, particularly in Missouri. In Missouri reservoirs, TP accounts for 79% of the cross-system variation in chlorophyll and there is a 5-fold range of Chl:TP ratios among long-term means. Residual variation is likely due to lake-specific conditions including sediment influx).). (Jones & Knowlton, 2005). A more recent analysis of water quality data within each of the ecological regions, conducted by MDNR, also indicates significant correlations between total phosphorus (TP) and chl-*a* (Figure 2). Correlations between total nitrogen (TN) and chl-*a* are generally not as strong, but are nevertheless significant.

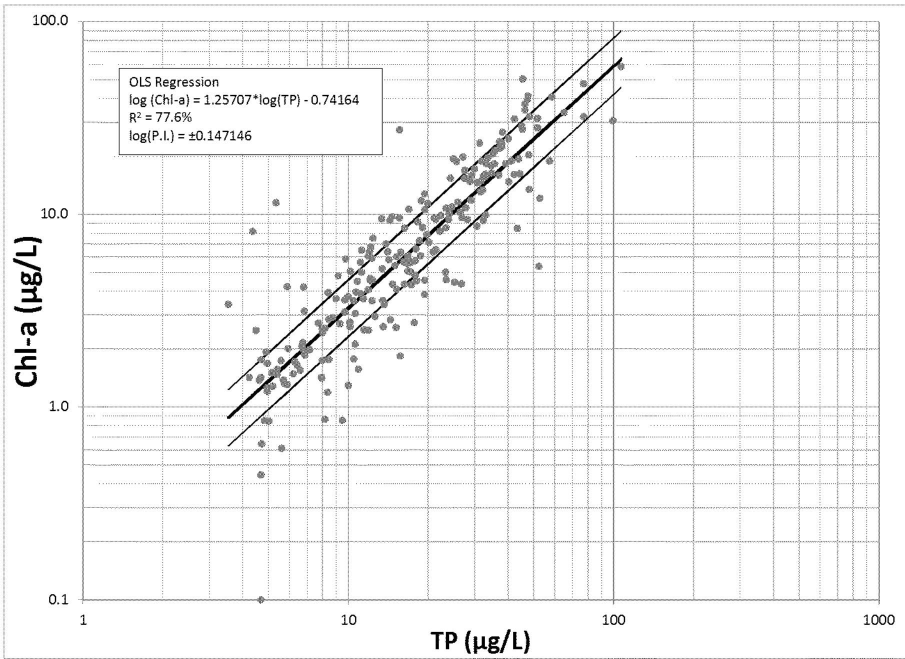

Figure 2. Chlorophyll-a - Total Phosphorus Plot of Annual Geomean Reservoir Data in the Ozark Highlands Region

While the biotic response to nutrient enrichment at specific concentration levels is relatively well established in reservoirs, the department is not recommending use of traditional fixed-threshold nutrient (phosphorus and nitrogen) criteria. As previously discussed, the effects of nutrient over-enrichment are systemic (i.e., nutrients, themselves, are not generally toxic and are actually required to support aquatic life). Linking causal variables (phosphorus and nitrogen) to detrimental impacts ultimately involves greater uncertainty and site-specific considerations than linking response variables (chl-*a*).

The department has adopted the position that nutrient criteria should be based on biological attributes. Specifically, the department is recommending that chl-*a* serve as the basis for establishing nutrient criteria. Chl-*a* is the most common method of measurement of the abundance of algae in a water body. Chl-*a* is also directly related to a number of factors directly impacting designated uses (e.g., low dissolved oxygen and algal toxins). Additionally, adopting chl-*a* resolves the issue that reservoirs exhibit variable sensitivity to nutrient enrichment based on their flushing rate, critical depth, sediment influx, and other factors.

Given the uncertainties concerning nutrient impairments, MDNR is also proposing the use of screening values to identify reservoirs in need of further evaluation. Under this approach an upper chl-*a* concentration would be established as the criterion above which designated uses are impaired (Figure 3). A lower set of screening values (chl-*a*, TN and TP) would also be set, below which designated uses are considered to be attained. Nutrient concentrations between the screening values and criteria represent the “gray zone” and would require a weight of evidence evaluation.

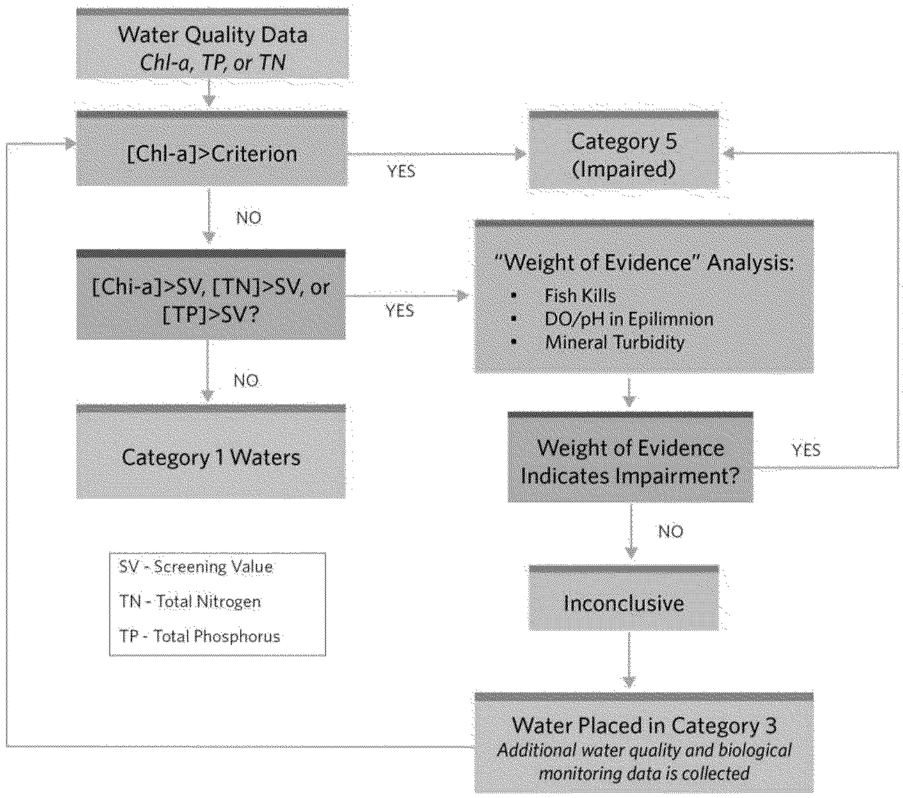

Figure 3. Screening Approach

This weight of evidence evaluation for aquatic life protection includes assessing the occurrence of harmful algal blooms, fish kills, wide diurnal fluctuations of dissolved oxygen, and high turbidity levels that may impact beneficial uses. In lakes that are sources for drinking water, it also includes the occurrence of disinfection byproducts in treated water, taste and odor issues, the presence of algal toxins, and significant impacts on water treatment plant operations. Lakes will be listed as impaired if one or more of these factors is determined to be significant to the point of impairing either aquatic life or drinking water these beneficial uses. Lakes found not to be impaired will be placed in Category 3 of MDNR's 305(b) report (i.e., water quality data are not adequate to assess the designated beneficial use).

The concept of a "gray zone" was widely discussed during the U.S. Environmental Protection Agency's (USEPA) expert workshop convened in April 2013. Some experts believed a "grey zone" is necessary, noting the uncertainty associated with establishing a single threshold value (USEPA, 2013). Such a concept has also been proposed by other states, including Virginia and Arizona. MDNR concurs with the findings at of USEPA's expert workshop and asserts that this approach provides a sound scientific rationale for protecting designated uses.

MDNR further adopts the position that criteria and screening values be expressed as geometric mean values. Geometric means will be used because nutrient concentrations have a log-normal distribution. The chl-*a* criteria will be based on a long-term duration as defined by at least 3 years of data. A long-term duration of three or more years is necessary to account for natural variations in nutrient levels due to climatic variability. (Knowlton & Jones, 2006). Additionally, two sets of screening values for chl-*a*, total phosphorus (TP) and total nitrogen (TN),) based on a long-term (i.e., minimum of 3 years) and short-term (i.e., 1 year) periods, provide additional opportunities to screen reservoirs for potential impairments. The magnitude of the short-term chl-*a* screening value is proposed to be equal to the magnitude of the chl-*a* criterion. The magnitude of the long-term chl-*a* screening value will be set to a higher value based on rationale provided below. Short-term and long-term TP and TN screening values are based on regional regressions and the magnitude of the respective chl-*a* screening values as described in the "Calculation of Screening Values" section.

Designated Uses

Rationale for the magnitude of chl-*a* criteria and screenerscreenerscreening values are provided below for public drinking water supply and aquatic life.

Public Drinking Water Supply

Eutrophication in lakes that serve as public drinking water supply can give rise to several issues, including taste and odor problems, higher treatment costs, and potential health hazards. The last impact may come in the form of cyanotoxins or precursors of disinfection byproducts, notably trihalomethane.

One potential approach for setting criteria protective of drinking water supplies is to target nutrient concentrations that limit algal blooms, which are closely linked to algal toxins and high levels of organic carbon that may be disinfection byproduct precursors. Algal bloom frequency is thought to be a better indicator of potential use impairment than trophic status alone (Heiskary and Walker, 1988). Some studies have suggested that algal bloom frequency increases exponentially when mean chl-*a* levels exceed 10 ug/L (Walker, 1985; Falconer, 1999; Downing et al., 2001). However, these findings are based on interpretations of relatively poorly defined relationships. Additionally, these studies may be more applicable to lakes than reservoirs. Downing et al. (2001) purposely excluded reservoirs from their study of algal blooms; potentially due to the fact that reservoirs typically respond differently to nutrient enrichment than natural lakes.

Another potential approach is to target chl-*a* levels that minimize compounds responsible for taste and odor issues. Two such compounds, geosmin (trans-1, 10 dimethyl-trans-9-decalol) and MIB (2-methyl isoborneol), have been strongly associated with blue-green algae blooms. Smith et al (2002) found a strong predictive relationship between geosmin and chl-*a* concentrations. From this relationship Smith et al (2002) provisionally suggested that taste and odor problems would cease when chl-*a* concentrations are maintained at a level below 10 µg/L (Figure 4). However, the Smith et al (2002) recommendation was based on an assumed odor threshold of 5 ng/L for geosmin, which varies between studies. For example, the American Water Works Association (2008) uses a geosmin threshold of 10 ng/L. Also, the Smith et al (2002) work was limited to a single shallow reservoir in Kansas; given the natural variations in how the physical, chemical and biological facets of reservoirs interact, the findings of this study may not be applicable to all water-bodies.

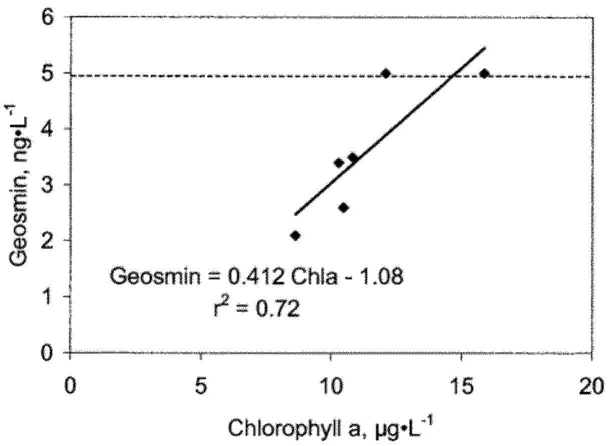

Figure 4. Relationship between station mean concentrations of geosmin and chlorophyll-a in Cheney Reservoir, USA. (From Smith et al (2002). The horizontal dotted line indicates an approximate threshold concentration of geosmin for human detection.)

For purposes of establishing a drinking water criterion, MDNR targeted a chl-*a* criterion to control microcystin. Microcystin is the most common toxin produced by cyanobacteria within algal blooms. A hepatotoxin, microcystin[1] has been documented to pose chronic and acute health risks to livestock, pets, and humans. The World Health Organization (WHO) has adopted a provisional guideline value for lifetime exposure of 1,000 ng/L (1.0 µg/L) for microcystin[2] (Falconer, et al., 1999). In a study of 241 lakes in Missouri, Iowa, northeastern Kansas, and southern Minnesota, Graham et al (2004) found that microcystin is common in lakes but generally at low levels. Reported median microcystin-LR concentrations in Missouri regions were at or below 2 ng/L (Table 2). Graham and Jones (2009), following up on the 2004 study, found that relatively few lakes in Missouri had microcystin concentrations greater than the WHO finished drinking water guideline of 1 µg/L. The mean chl-*a* concentrations associated with microcystin-LR levels ranging from the detection limit (0.1 µg/L) to the WHO guideline (1 µg/L) was reported as 26 µg/L (Table 3).

Based on findings discussed above, the magnitude of the chl-*a* criteria and screeningscreening values for drinking water supplies are summarized in Table 4. Long-term and short-term screening valuesscreening values for TP and TN are based off of regional regressions and the chl-*a* screening valuesscreening values as summarized in the "Calculation of Screening Values" section.

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[1] Microcystins are a family of compounds. The most extensively studied member is microcystin-LR (5R,8S,11R,12S,15S,18S,19S,22R)-15-[3-(diaminomethylideneamino)propyl]-18-[(1E,3E,5S,6S)-6-methoxy-3,5-dimethyl-7-phenylhepta-1,3-dienyl]-1,5,12,19-tetramethyl- 2-methylidene-8-(2-methylpropyl)-3,6,9,13,16,20,25-heptaoxo-1,4,7,10,14,17,21-heptazacyclopentacosane-11,22-dicar boxylicacid.

[2] The guideline value is based on the following assu mptions: Average adult body weight (bw) is 60 kg, a provisional total daily intake (TDI) set at 0.04 µg kg $^{-1}$, of which a proportion (P) of 0.8 is allocated to dr inking water, and water consumption of 2 L d^{-1}. It is calculated as follows: $Guideline \quad lue \quad = \frac{TI*bw*P}{L}$,which comes to 0.96 µg L^{-1}, and is rounded up to 1.0 µg L^{-1}.

Table 2. Regional Medians and Ranges of Microcystin Values (Adapted from Graham and Jones (2004)).

Region	Microcystin-LR (ng/L)		
	n	Median	Range
Ozark Highlands	92	0[a]	0-43
Osage Plains	111	0[a]	0-189
Dissected Till Plains	439	2[b]	0-2,933

n indicates the number of lake visits in each region . Letters indicate significant differences in medi an concentrations (Kruskal-Wallis, $p<0.01$).

Table 3. Comparison of Chlorophyll Levels Among Three Microcystin Concentration Categories (Adapted from Graham and Jones (2009)).

Microcystin-LR (ng/L)	Chlorophyll (µg/L)		
	n	Mean	Range
nd	1,082	11[a]	1-342
0.1-1	271	26[b]	1-306
>1	49	46[c]	3-140

n indicates the number of lake visits in each region . Letters indicate significant differences in mean values.

Table 4. Chlorophyll-a Criterion and Screening ValuesScreeners for Drinking Water Supplies

	Magnitude (ug/L)	Rationale
Criterion	26	Protects for WHO microcystin-LR guideline of 1.0 µg/L based on Graham and Jones (2009)
Long-Term Screening Value	10	Conservative literature based value protective of algal blooms and taste and odor issues
Short-Term Screening Value	26	Same value as criterion with more conservative averaging period

Protection of Aquatic Habitat

Lakes in Missouri provide habitat for a variety of fish species, most of which are naturally reproducing within the lakes. Table 5 lists and describes fish species which are common in smaller lakes (<1,000 acres) (MDC, 2012).

Table 5. Common fish species found in small lakes of Missouri.

Common Name	Scientific Name	Habitat and other comments[5]
Common Carp	*Cyprinus carpio*	Invasive species. Introduced from Asia in 1879. Abundant in man-made impoundments that are highly productive as a result of runoff from heavily fertilized farmlands or other pollutants. Often compete for food with more desirable

[5] Summarized from descriptions by Pflieger (1975).

		species. Feeding habits result in deterioration of habitat through increased turbidity and destruction of aquatic vegetation. Feeding activity may result in increased nutrient loading.
Gizzard Shad	*Dorosoma cepedianum*	Appears in clear and turbid waters, prefers those where fertility and productivity are high.
Channel Catfish	*Ictalurus punctatus*	Common in large rivers. Hatchlings have low survival rate in clear waters, higher in turbid waters. Therefore they need periodic restocking in some lakes.
Green Sunfish	*Lepomis cyanellus*	Tolerates wide range of conditions, including extremes of turbidity, dissolved oxygen and temperature. Among the first to repopulate prairie streams following droughts.
Bluegill	*Lepomis macrochirus*	Intolerant of continuous high turbidity. Thrives in clear water where aquatic plants or other cover is present.
Redear Sunfish	*Lepomis microlophus*	Does best in warm, clear waters with no noticeable current and an abundance of aquatic plants.
Largemouth Bass	*Micropterus salmoides*	Thrives in warm, moderately clear waters with no current.
White Crappie	*Promoxis annularis*	Commonly in areas with standing timber or other cover. Spring spawning in shallow water near upper ends of coves.
Black Crappie	*Promoxis nigromaculatus*	Sporadic distribution, most prevalent in large Ozark reservoirs. Less common and less tolerant of turbidity and siltation than White Crappie.

While the ideal habitats for these species vary considerably, what they generally have in common is that they require some degree of aquatic productivity to thrive. Most of these species do well in eutrophic conditions. There is substantial literature that describes a need for higher nutrient concentrations to support healthy fisheries (Knowlton & Jones, 2003). Jones and Hoyer (1982) found a strong positive relationship between chl-*a* concentrations, up to 70 µg/L, and sport fish yields in Missouri and Iowa lakes. Michaletz et al (2012) reported that growth and size structure of sport fish populations increased with water fertility, due to abundance of prey in more fertile waters. However there is an upper limit beyond which fish population declines. They also reported, among many other findings, that for largemouth bass and black crappie, fish size distributions had a threshold for chl-*a* of 40 to 60 µg/L, above which fish sizes declined. Additionally, largemouth bass and redear sunfish Catch Per Unit Effort (CPUE) were particularly low when TP exceeded 100 µg/L. This approximates the threshold of hypereutrophy (Carlson & Simpson, 1996; Jones, Obrecht, et al., 2008).

In addition to the above findings, Egertson and Downing (2004) reported that in Iowa lakes, high concentrations of chl-*a* were associated with a decline in fish species diversity. Specifically, on a chl-*a* gradient of 10 to 100 µg/L, CPUE for common carp and other benthivore species went up. This appeared to be at the expense of CPUE for more desirable species, notably bluegills and black crappie. While the declines of the latter were not statistically significant, the study suggests that highly eutrophic conditions disfavor piscivores, which are mainly visual feeders.

Following a review of these and other findings, staff from the Missouri Department of Conservation (MDC) and the University of Missouri (MU) provided chl-*a* concentrations that would support warm water fisheries in smaller lakes (Table 6). The concentrations provided by MDC and MU for the Plains are conservative to support sports fisheries, rather than maximizing sport fish harvest. Sport fish biomass probably does not peak at less than 100 ug/L TP (about 39 ug/L chl-*a*) (Ney 1996). For the Ozark Highlands, MDC and MU provided a lower chl-*a* concentration of 15 ug/L, given that these waters are situated in less fertile landscapes and large reservoirs contain species characteristic of clear Ozark streams that are likely more sensitive to high nutrient concentrations. The Ozark Border section represents a transition zone between the Plains and Ozark Highlands; therefore, MDC and MU provided a chl-*a* criterion intermediate to the other two sections.

Table 6: MDC and MU recommendations for chl-*a* criteria for Missouri lakes.

Lake Ecoregion	Chl-*a* (µg/L)
Plains	30
Ozark Border	22
Ozark Highlands	15

Further consideration was given to the prevailing lake trophic conditions that were characteristic of each region. Although trophic status, itself, is not the same as a water quality index, the use of prevailing trophic conditions offers an approach for establishing regional goals and expectations (Carlson, 1977). In the Plains, most lakes are eutrophic whereas in the Ozark Highlands, most lakes are mesotrophic, and several are oligotrophic. Lakes in the Ozark Border region are a transition between mesotrophic and eutrophic. These regional differences in water quality reflect variations in geology and topography across the state. The concept of criteria varying with region was set forth in EPA's *Nutrient Criteria Technical Guidance Manual* (2000) which lists the Missouri Plains region as part of Ecoregion XI – The Central and Eastern Forested Uplands, while the Ozark Highlands are considered to be in Ecoregion IX – Southeastern Temperate Forested Plains and Hills. Trophic state thresholds proposed by Jones et al. (2008) for Missouri reservoirs are presented in Table 7.

Table 7. Trophic state thresholds for Missouri reservoirs (Jones et al. 2008)

Trophic State	Upper Limit of Trophic State for Chl-*a* (ug/L))
Oligotrophic	3
Mesotrophic	9
Eutrophic	40

Criteria for chl-*a* in the Plains is set at 40 µg/L to approximate the threshold between eutrophic and hyper-eutrophic conditions (Jones, et al., 2008). Suggested criteria for the Ozark Highiland and Border regions are based on information provided by the MDC and MU. Long-term screening values are more conservatively based on central values corresponding to the prevailing trophic conditions in each region. The suggested long-term chl-a screening values are 20 µg/L for the Plains, 9 µg/L for the Ozark Border region, and 7 µg/L for the Ozark Highlands. Chl-*a* criteria and screening values are summarized in Table 8. Long-term and short-term screening values for TP and TN are based off of regional regressions and the chl-*a* screening values as summarized in the "Calculation of Screening Values" section.

Table 8. Chlorophyll-*a* CriterioaCriterion and Screeners for Aquatic Life

Limit Type	Region	Chl-*a* (ug/L)	Rationale
Criterion	Plains	40	Protects sports fisheries and reflects prevailing trophic conditions within the region
	Ozark Border	22	
	Ozark Highland	15	
Short-Term Screening Value	Plains	40	Same value as criterion with more conservative averaging period
	Ozark Border	22	
	Ozark Highland	15	
Long-Term Screening Value	Plains	20	Central values corresponding to prevailing trophic conditions within the region
	Ozark Border	9	
	Ozark Highland	7	

Calculation of Screening Values

Data for this analysis were collected by the Lakes of Missouri Volunteer Program (LMVP) and the Statewide Lake Assessment Program (SLAP). The data used were from the years 2003 – 2013. A brief statistical description is in Table 9.

Table 9: General statistics for lake data that were employed for this report.

Region	Number of Lakes	Yearly Geomeans (n)	Parameter Concentration Averages (Ranges)		
			TP (µg/L)	TN (µg/L)	Chl-a (µg/L)
Plains	140	611	61 (9 – 302)	909 (305 – 2660)	25 .1 (0.3 – 133.2)
Ozark Border	31	87	59 (5 – 291)	834 (243 – 2781)	21.7 (0.9 – 100.4)
Ozark Highlands	48	228	21 (4 – 107)	450 (75 – 1279)	10.0 (0.0 – 58.7)

To derive the long-term and short-term screening values for TN and TP, regressions were run with chl-*a* as the response variable. To account for seasonal variation of chl-*a* response and to ensure sufficiency of data for each ecoregion, yearly geometric means of TN, TP, and chl-*a* concentrations for individual lakes were treated as the data points. This approach is consistent with criteria derivation methodology published by EPA (2010).

Each of the regression equations was recalculated using iterative weighted least squares one time (Helsel & Hirsch, 2002). TN and TP screening values were then derived by back calculating the regression equations using the chl-*a* values that were determined for each of the ecoregions. Results are in Tables 10a and 10b.

Table 10a: Regressions of $\log_{10}$ (Chl-*a*) response to $\log_{10}$ (TP) using annual geometric means.

Region	Slope	Intercept	R^2 (%)	Short Term (µg/L)		Long Term (µg/L)	
				Chl-*a*	TP	Chl-*a*	TP
Plains (AQL)	1.03824	-0.456854	80.5	40.0	96	20.0	49
Plains (DWS)				26.0	64	10.0	25
Ozark Border	1.06947	-0.56602	89.3	22.0	61	9.0	26
Ozark Highlands	1.28686	-0.77184	92.8	15.0	33	7.0	18

Table 10b: Regressions of $\log_{10}$ (Chl-*a*) response to $\log_{10}$ (TN) using annual geometric means.

Region	Slope	Intercept	R^2 (%)	Short Term (µg/L)		Long Term (µg/L)	
				Chl-*a*	TN	Chl-*a*	TN
Plains (AQL)	1.64908	-3.53766	80.9	40.0	1,308	20.0	857
Plains (DWS)				26.0	1,008	10.0	564
Ozark Border	1.76583	-3.9239	81.4	22.0	960	9.0	579
Ozark Highlands	1.53273	-3.1842	69.6	15.0	699	7.0	425

Discussion

The department's recommendations are based on the goal of establishing scientifically defensible lake nutrient criteria that are clearly linked to designated uses. The approach recommended herein provides an alternative to traditional fixed-threshold criteria, which too frequently lead to false positives (false declaration of use impairment) and false negatives (false declaration of use attainment).). Rather, this approach allows the department to focus its efforts and resources on those reservoirs most likely in need of restoration.

Owing to the complexities and uncertainties of linking causal variables (phosphorus and nitrogen) to response variables and designated uses, the recommended criteria are based on biological attributes (i.e., chl-*a*). Chl-*a* is an ideal criterion because it is directly related to a number of factors that have a direct effect on a reservoir's ability to meet its designated use (e.g., algal blooms, algal toxins, low dissolved oxygen, and taste and odor). Using chl-*a* criteria as a surrogate for nutrient criteria avoids falsely identifying lakes as impaired where nutrient levels may be high but algal production is constrained by low autotrophic potential (e.g., fast flushing and low critical depth).

To limit the possibility of false negatives, the department is further recommending the use of screening values. Proposed screening values were conservatively established such that there is a high degree of confidence that reservoirs with nutrient concentrations below these levels are not impaired by nutrients. Where screening values are exceeded but the chl-*a* criterion is not, the department is recommending a weight of evidence evaluation. Such an evaluation would consider additional factors such as the occurrence of harmful algal blooms and fish kills to more definitively determine whether or not the designated use is or is not being attained.

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